NATIONAL BUREAU OF STANDARDS REPORT

9636

PERFORMANCE TEST

OF TWO DOMESTIC HUMIDIFIERS

Manufactured by the
Auto-Flo Corporation
of Detroit, Michigan

by

Joseph C. Davis
and
Walter M. Ellis

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D. C., 20234.

[2] Located at Boulder, Colorado, 80302.

[3] Located at 5285 Port Royal Road, Springfield, Virginia 22151.

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Sponsored by the

Department of Health, Education, and Welfare
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1. Introduction

At the request of the Food and Drug Administration, the water evaporative capacities of two humidifiers were measured by the National Bureau of Standards. The tests were performed using proposed ARI Standard 610 for Central System Humidifiers as a guide. This Standard, which is in the process of being evaluated by a project committee of the Air Conditioning and Refrigeration Institute, has not been adopted by that Institute, but was used during the testing wherever feasible because it reflects the background of the members of the project committee who have extensive experience in this field. So far as the National Bureau of Standards has been able to determine, there is no other standard for testing humidifiers of this type in the United States.

The scope of the investigation included not only the determination of the evaporative capacities of the two humidifiers under normal furnace operating conditions but also:

1) The study of effects of change of air velocity at the humidifier, of the amount of moisture in the air at the inlet to the test apparatus, of the temperature of the moving air in the duct at the humidifier, and of the static pressure in the duct at the humidifier.

2) An estimate, based on theoretical considerations and experience of those conducting the tests, of the effect of evaporation rates on the relative humidity in an average house when variables such as outside temperature, wind, and house-size, are taken into consideration.

2. Description of Test Specimens

The two humidifiers were supplied by the Food and Drug Administration. The larger of the two, Model 40, is 15-1/2 x 14 x 7 in. It is designed to fit on to the side of an air-supply duct from the furnace. When mounted, the humidifier fits up to a rectangular hole in the duct through which the air flowing through the duct is brought by an electrically-operated fan through a metal honey-combed meshwork approximately 8 x 8 in., over which water drips continuously. (This meshwork is called an evaporation pad by the Auto-Flo Corporation.) The water flow is spread evenly across the face of the meshwork, accomplished by means of six holes evenly spaced laterally in a reservoir along the top of the meshwork. The water is supplied to this reservoir by means of a pump from another reservoir in the bottom of the device--hereinafter known as the supply reservoir--which is fed from the house water line. The fan is a propeller type and has five blades. It draws the air to be moistened through the wet meshwork after which it is returned through two rectangular and vertical openings, one on each side of the meshwork, and thence back into the duct where it flows into the complex duct system of the house.

Nameplate information is as follows:

Auto-flow; Power Humidifier; Model No. 40; Serial No. R-14128; Cycles - 60; Phase - 1; Control - 24 volts; Motor - 115 volts; Total Amps. - 1.5.

During operation of Model 40 in a test of the apparatus where the static pressure was 0.15 in. Hg, measurements were made of the voltage and current at the humidifier with the following results:

Voltage: 120 volts
Current: 0.5 amp

The smaller humidifier of the two, Model 150, is approximately 4 x 5 x 16 in. in outer dimensions. It is also designed to be fitted to an opening in the side of the air-supply duct of the furnace. About 10 in. of the device extends into the duct, however, and evaporation occurs as the moving air in the duct passes over the 5 wet wicks, or evaporative plates, made of cloth material, which were provided with the specimen. These plates, each 7 x 1-3/4 in. in size, comprising 12-1/4 sq. in. of wetted, air-bathed area, are aligned parallel to the direction of air flow. Each plate (or wick) extends down into a water supply reservoir in the lower portion of the humidifier. The water in the reservoir is maintained at a pre-set level of 1-1/2 to 2 in. by means of an automatic device which operates and calls for more water from the house water system when it gets below the pre-set level.

3. Test Methods and Procedures

3a. Model 40 Humidifier

The Model 40 humidifier was tested in the apparatus shown in figure 1. The apparatus was housed in a large test chamber in which the dry and wet bulb temperatures were held at about 70 and 53 °F, respectively. This combination of dry and wet bulb temperatures is equivalent to about 30 percent relative humidity at 70 °F.

The air at the intake of the apparatus was drawn through a 12 in. circular duct and propelled by a blower through a transite-covered, cubical chamber, 2 ft on each side, in which electrical resistance elements heated the air to about 140 °F. This temperature is approximately typical of those occurring under a variety of conditions in the plenum of a house furnace. The air was blown through a duct, 10 in. in diameter and insulated on the outside with fiber-glass, where it was well mixed by an air-mixing device consisiting of two sections. The air then passed into a rectangular duct on which the humidifier was mounted. Some of the air stream was directly conditioned by the humidifier, and mixed in the stream of air which passed out through the end of the duct.

The dry and wet bulb temperatures at the intake to the apparatus were measured with three thermocouple psychrometers spaced evenly across the horizontal diameter of the cross sectional area of the circular duct. Potentiometric measurements showed that the psychrometric readings were closely the same at the 3 locations throughout the testing. The dry bulb temperatures of the air at a position almost immediately upstream of the humidifier were measured by an array of 5 thermocouples. Each thermocouple was fabricated from No. 30 copper constantan thermocouple wire, calibrated at the National Bureau of Standards. Means were taken to eliminate errors due to heat conduction along these wires. To shield the 5 thermocouples from the radiation of the resistance heaters upstream in the cubical chamber, and to avoid radiation from the thermocouple junctions to the colder walls of the rectangular duct, small cone-shaped shields made of reflective aluminum were placed on each junction with the apex of the shield pointing upstream. The readings of the 5 thermocouples agreed with each other usually within 0.2 deg F indicating that the air was well mixed. As a means for assuring that the radiation effects were not appreciable, a calibrating device consisting of polished aluminum shields was used to measure and check these temperatures. Chromel constantan

thermocouple wires were used in this device to minimize conduction errors, and a precision-type potentiometer was employed. Results of these measurements showed that the average temperature indication for the 5 thermocouples agreed to within 2 deg F with the temperature indicated by the calibrating device.

A self-balancing potentiometer carefully adjusted, was used to determine the temperature for each thermocouple used in the apparatus. To determine that the indications of this instrument were correct within the temperature span used, two water baths, both in Dewar flasks were used. The temperature of the water in one of the baths was approximately 70 °F, and in the other approximately 140 °F. In each bath was placed an NBS calibrated mercury-in glass thermometer and a copper constantan thermocouple. For both baths, the indications of the potentiometer agreed with the thermometer readings within 0.1 °F and usually within 0.05 °F. An ice-bath in a Dewar flask was also used. This bath indicated 32.0 °F throughout the tests.

Measurement of the air velocity in the duct was determined with a pitot tube at a point downstream near the humidifier. Before the tests were started, both a vertical and horizontal scan with this tube showed the velocity distribution in the duct to be nearly uniform at the plane of measurement.

The evaporation rate was determined by measurement of the amount of water fed into the supply reservoir over a period of 3 to 4 hours. Readings were determined gravimetrically every half-hour by means of a beam scale and averaged. Water was supplied to the reservoir from an upturned, 5-gallon water jug and the amount regulated by a "chicken feeder" device which allowed water to enter the supply reservoir in small increments as needed to maintain a substantially constant level in the reservoir. The rate of water-supply to the reservoir was reasonably steady, as shown in Table 1 for two test runs made on the Model 40 humidifier.

Table 1

Pounds of Water Evaporated

During Half Hour Period

No. of Period	1	2	3	4	5	6	7	8	Avg.
Test 9	1.66	1.63	1.69	1.65	1.67	1.70	1.67	1.70	1.67
Test 10	1.71	1.74	1.77	1.63	1.71	1.81			1.73

The beam scale resolution was such that it could be read to the nearest 0.01 lb.

The system water in the laboratory was used to supply the humidifier. There was little evidence of corrosion. After the tests had been performed a small amount of white, flocculent residue was noted in the bottom of the supply reservoir, but it was not of sufficient amount to affect the evaporation rate appreciably. An analysis of the water supplied during the year 1966 to the National Bureau of Standards in Gaithersburg, Maryland where the tests were made, is presented in Table 2. Analysis of the supply water in 1967 would not be much different. The information of Table 2 was prepared by the Washington Suburban Sanitary Commission.

TABLE 2

MINERAL AND CHEMICAL ANALYSES - P.P.M.
POTOMAC FILTRATION PLANT
TAP WATER

	1966 AVERAGE
Total Solids	216
SiO_2	4.2
Al	0.03
Fe (Total)	0.01
Ca	37.4
Mg	7.1
Mn	0.00
SO_4	64.8
Chloride	17.2
NH_3	0.00
Fluorides	0.93
pH	7.8
Hardness (Total)	125
Alkalinity (Total)	69.1
Alkalinity CO_3	0.2
Alkalinity HCO_3	68.9
D. O. % Sat.	98
CO_2	2.0
Chlorine Residual	1.50
Temp. Water °F.	61
Na	17.3
K	<1.0

The primary test was made with a dry bulb air-temperature of 70 °F and a wet bulb temperature of 53 °F (30 per cent RH) at the inlet to the apparatus, and an air temperature of 140 °F in the duct at the humidifier. Air velocity was 800 fpm. The static pressure in the duct at the humidifier was 0.15 in. WG. The nominal conditions of this test are shown in Table 3. The test is listed as No. 9 in this Table.

The conditions for supplementary tests which were performed are also listed in Table 3.

Table 3

Nominal Conditions for the Tests

Test No.	Air Velocity (fpm)	Dry Bulb Temp. in Duct at Humidifier (°F)	Dry Bulb Temp. at Inlet (°F)	Wet Bulb Temp. at Inlet (°F)	Relative Humidity at Inlet (%)	Static Pressure in Duct at Humidifier (in. W.G.)
1	800	140	70	53	30	0
2	500	140	70	53	30	0
3	900	140	70	53	30	0
4	800	140	70	47	10	0
5	800	140	70	50	20	0
6	800	120	70	53	30	0
7	800	150	70	53	30	0
8	800	140	70	48	15	0
9	800	140	70	53	30	.15
10	500	140	70	53	30	.15
11	900	140	70	53	30	.15

3b. Model 150

Essentially the same procedures were followed for testing the Model 150 Humidifier. Exceptions are noted below.

(1) The rectangular duct housing the humidifier was turned so its long dimension was horizontal.

(2) The rate of air flow, which was measured by pitot tubes, varied at different positions alongside and above the reservoir. As a result of the asymmetrical configuration of the area through which the air traveled, the air velocity was not uniform across the plane of measurement. This plane was about 6 in. downstream from the humidifier and measurements were made in accordance with the positions shown in figure 2. The Air Conditioning and Refrigerating Institute Standard required that the air velocity be 800 fpm at the humidifier, but tests were made at velocities of about 650, 800, and 1000 fpm at positions just downstream of the plates and at the same approximate level as the plate centers. These positions are designated as positions 6, 7, 8, and 9 in figure 2. Upon completion of the tests on this model, pitot measurements were made at the end of the duct. The volume rate of flow calculated from these measurements showed reasonable agreement with that determined by measurements at stations 1 to 16 immediately downstream from the reservoir and plates. It is of interest to note that in all three cases the average velocity throughout the open area in the plane of measurement was about equal to the average of velocities observed at positions 6, 7, 8, and 9.

The flow of water from the supply jug into the humidifier in all tests was reasonably steady as indicated by the data of Table 4.

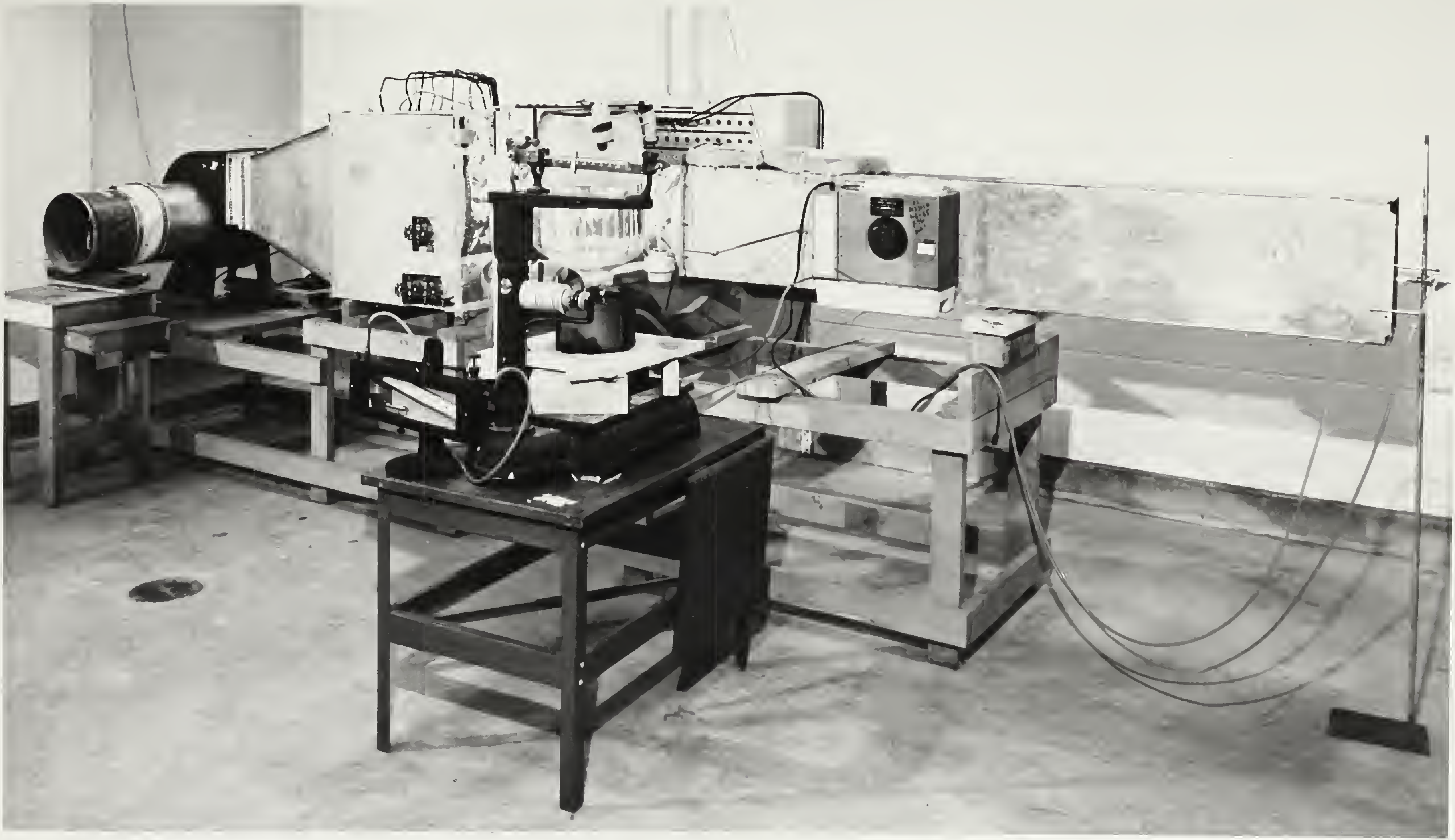
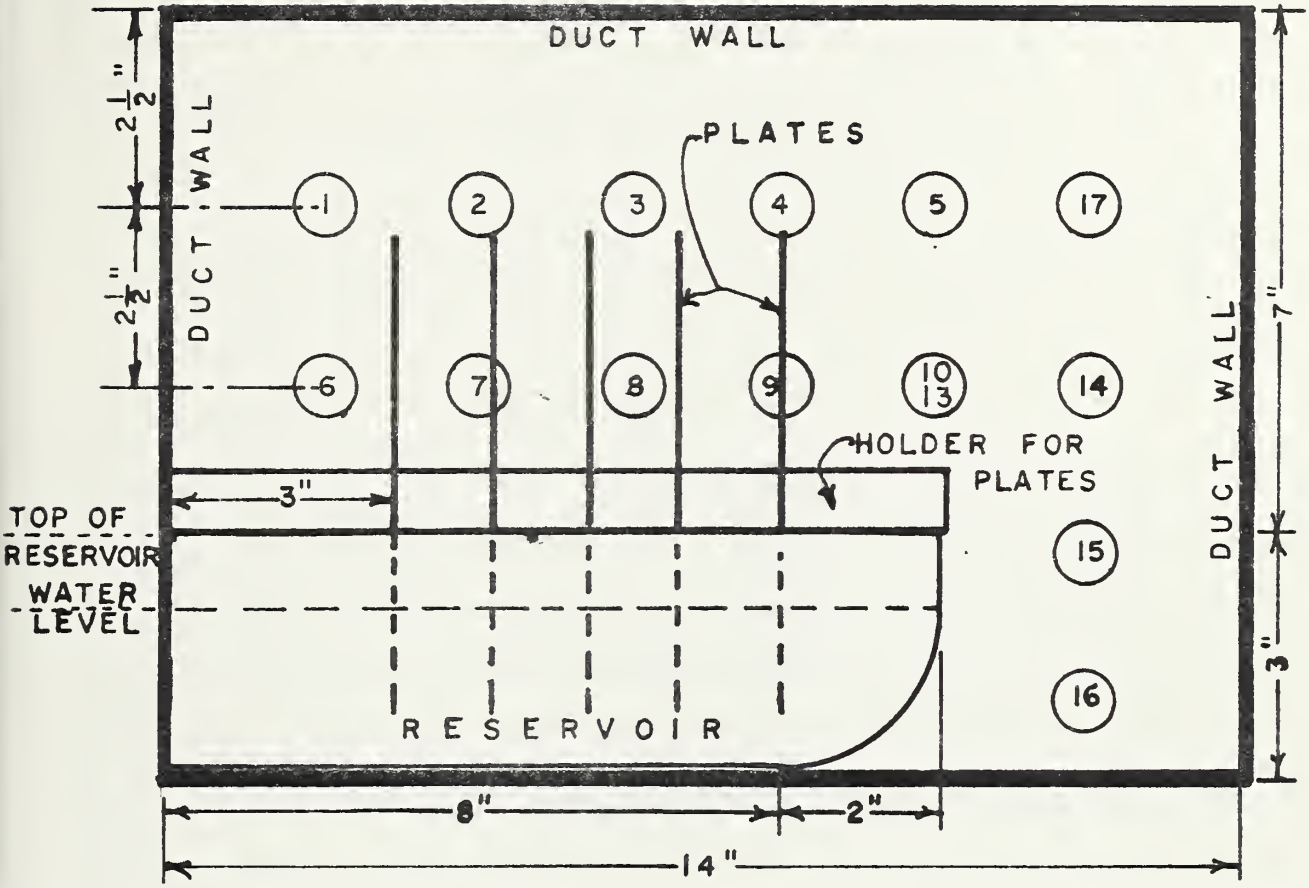


Figure 1. Apparatus used for testing Model 40 and Model 150 humidifiers. Model 40 is shown mounted on the side of the duct.



VIEW OF PITOT TUBE POSITIONS
LOOKING INTO END OF DUCT

Figure 2.

Table 4

Pounds of Water Evaporated During Half-Hour Periods

No. of Period	1	2	3	4	5	6	7
Test 1 A		0.82*		.81*		.80*	.35
2 A		.70*	.30	.22	.53	.25	.29
3 A	.41	.42	.44	.46	.44	.39	--

	8	9	10	11	12	13	14	Avg.
1 A	.37	.44	.39	.40	.33	.41	.41	.40
2 A	.38	.23	.17	--	--	--	--	.31
3 A	--	--	--	--	--	--	--	.43

* Hourly period

Precautionary measures were taken throughout the testing of both models to assure that there was sufficient water in the supply reservoir. For the larger model, the cover over the top reservoir was removed a number of times during the test to determine if water was coming from the lower (supply) reservoir through the pump system. For the smaller model, the cover-plate over the chamber that distributed water down into the reservoir was removed occasionally throughout each test for inspection to determine water level. The level was always about 2 in. For the smaller model, about one hour was required to assure full wetting of the wicks; this time was allowed in all cases before taking capacity data. There was no indication of water leakage from the humidifier to the floor during any of the tests.

The fan motor was energized continuously during the tests and rotor shaft rotation was noted a number of times during testing.

4. Results

4a. Model 40

Table 5 lists the results of the primary test and of supplementary tests on Model 40. The results of the primary test are listed first in the table.

TABLE 5

Results of Tests on Model 40

Test No.	Nominal Air Velocity (fpm)	Actual Air Velocity (fpm)	Static Pressure In Duct (in. W.G.)	Dry Bulb Temp. at Inlet (°F)	Wet Bulb Temp. at Inlet (°F)	Relative Humidity at Inlet (%)	Temp. of Moving Air at Humidifier (°F)	Rate of Water Evaporation (lb/hr)	(gal/hr)	(gal/day)
9.	800	790	0.15	70.6	53.2	29.5	140.2	3.36	0.40	9.6
1.	800	790	0	70.4	53.2	30.0	140.1	2.93	0.35	8.3
2.	500	540	0	70.1	52.6	27.5	140.0	3.12	.38	8.1
3.	900	890	0	70.3	52.7	28.0	139.9	2.79	.33	7.9
4.	800	780	0	69.9	47.6	11.5	139.7	3.17	.38	9.1
5.	800	790	0	69.8	50.0	19.4	140.1	3.11	.37	8.9
6.	800	790	0	70.5	53.0	28.0	120.4	2.27	.27	6.5
7.	800	790	0	69.9	52.7	29.5	150.1	3.26	.39	9.4
8.	800	790	0	69.5	48.3	14.4	140.0	3.15	.38	9.1
10.	500	520	0.15	69.8	53.2	29.5	139.9	3.46	.42	10.0
11.	900	900	0.15	70.4	53.6	30.5	139.5	3.03	.36	8.8

The table shows that the rate of evaporation averaged 9.6 gal./day for Model 40 during the primary test.

From the data of this test and the supplementary tests, curves were drawn as a means of illustrating the effect of change in air velocity, in static pressure in the duct at the humidifier, in air-temperature at the humidifier, and in relative humidity of the air at the inlet to the apparatus. The curves of figure 3 show that the evaporation rate decreased as the duct air velocity increased. They also showed that there was an appreciable increase of the evaporative rate when static pressure in the duct was raised from zero to 0.15 in. W.G. The curve of figure 4 shows a linear increase of evaporation rate with rise in temperature of the air at the humidifier and the curve of figure 5 shows that there was a non-linear decrease in evaporation rate as the relative humidity at the inlet to the apparatus was raised.

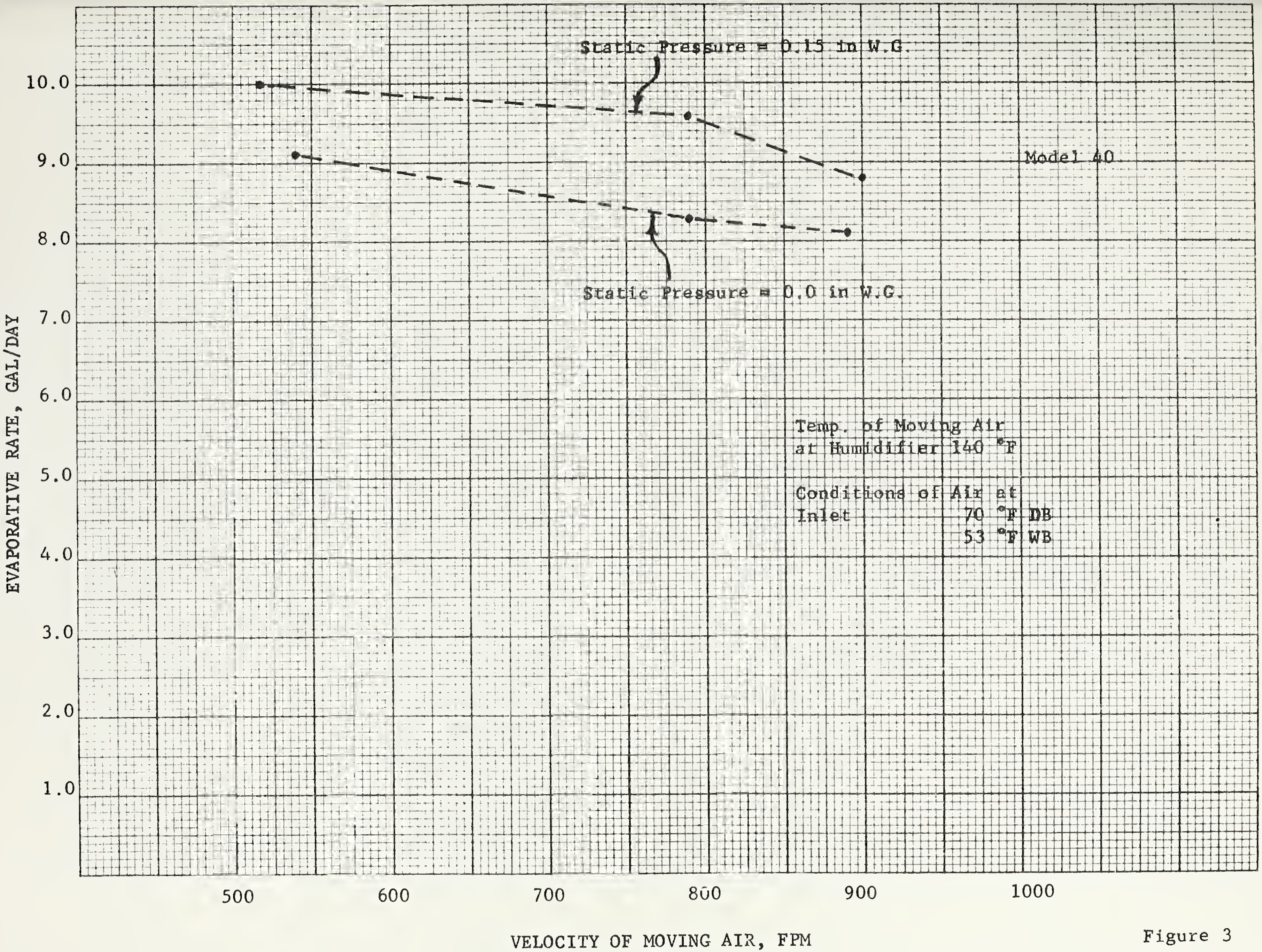
4b. Model 150

The results of the primary and two supplementary tests on Model 150 are shown in Table 6.

The curve of figure 6 shows the effect of change in air velocity across the plates of the Model 150 humidifier. It shows an increase of evaporation rate with increase in velocity of moving air.

Table 6

Test No.	Air Velocity Nominal (fpm)	Air Velocity Actual (fpm)	Static Pressure In Duct (in. W.G.)	Dry Bulb Temp. at Inlet (°F)	Wet Bulb Temp. at Inlet (°F)	Relative Humidity at Inlet (%)	Temp. of Moving Air at Humidifier (°F)	Rate of Evaporation $\left(\frac{lb}{hr}\right)$	$\left(\frac{gal}{hr}\right)$	$\left(\frac{gal}{day}\right)$
1A	800	790	0.15	70.5	53.1	28.3	139.8	0.79	0.095	2.3
2A	700	690	0.15	69.4	52.5	28.6	139.4	.61	.073	1.8
3A	1000	1020	0.15	69.6	52.7	29.2	137.0	.85	.102	2.5



Static Pressure = 0.15 in W.G.
Static Pressure = 0.0 in W.G.
Model 40
Temp. of Moving Air
at Humidifier 140 °F
Conditions of Air at
Inlet 70 °F DB
53 °F WB
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
EVAPORATIVE RATE, GAL/DAY
500
600
700
800
900
1000
VELOCITY OF MOVING AIR, FPM

Figure 3

HUMIDIFIER ON RATE OF EVAPORATION

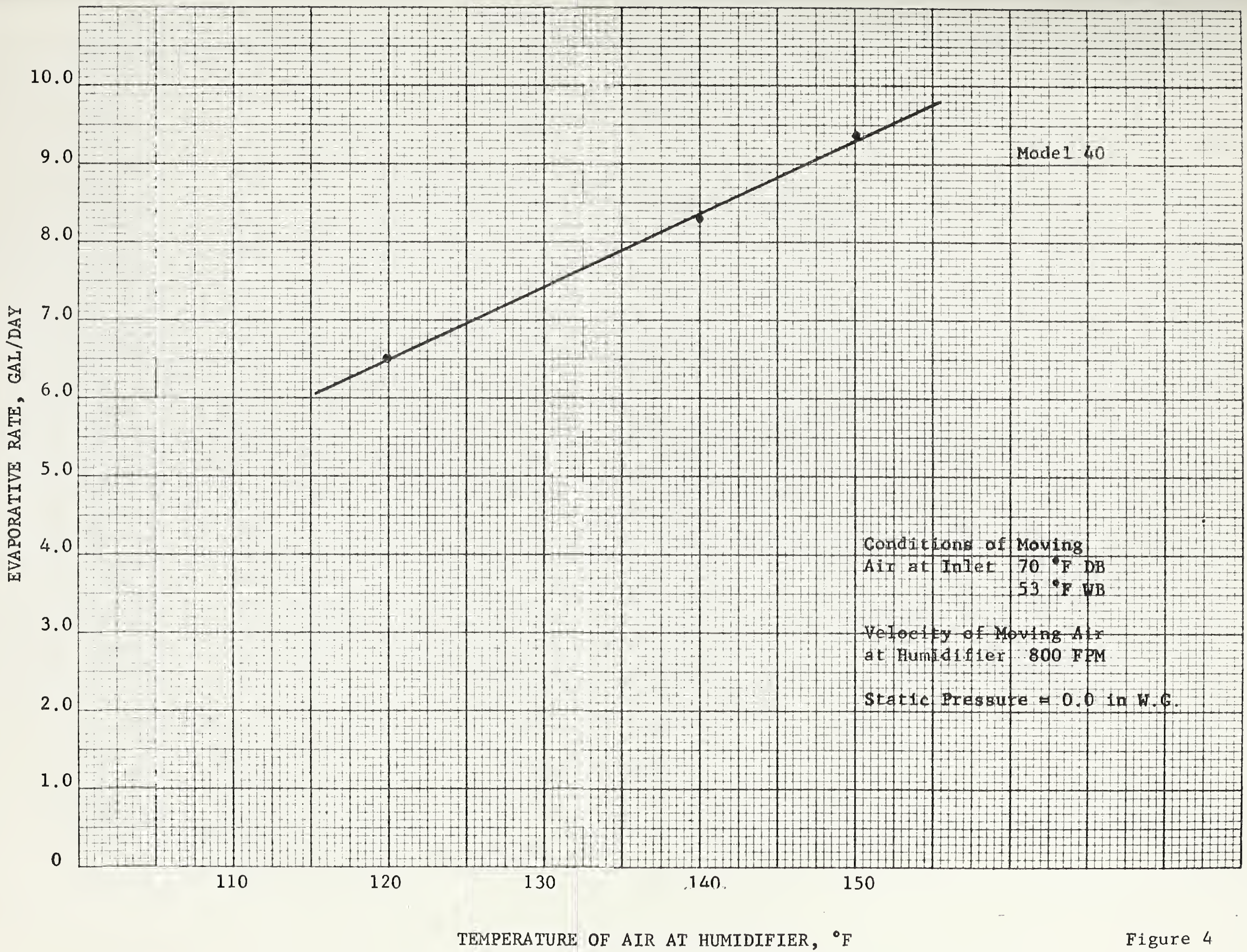


Figure 4

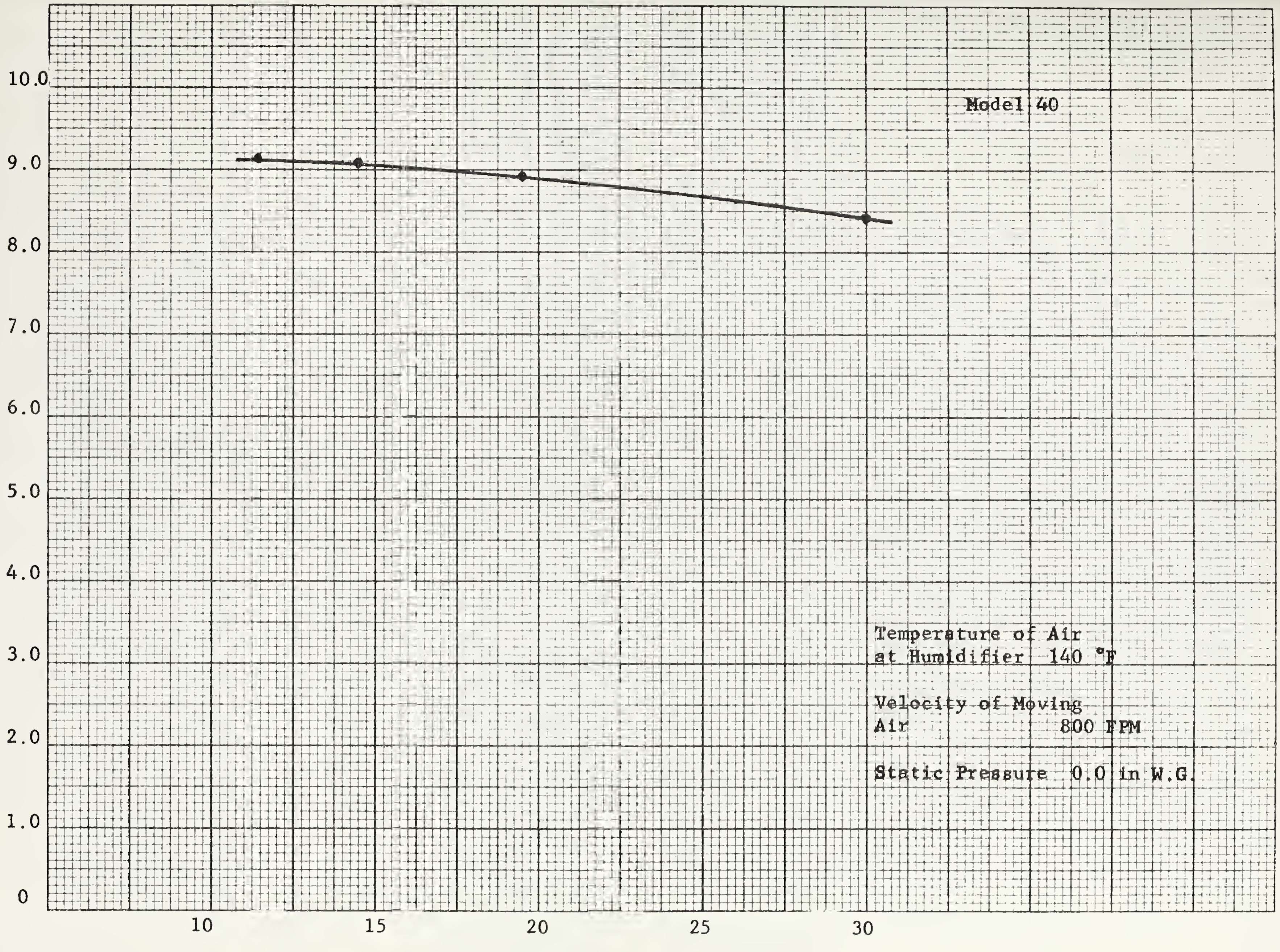

10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
10
15
20
25
30
Model 40
Temperature of Air
at Humidifier 140 °F
Velocity of Moving
Air 800 FPM
Static Pressure 0.0 in W.G.
RELATIVE HUMIDITY, PERCENT

Figure 5

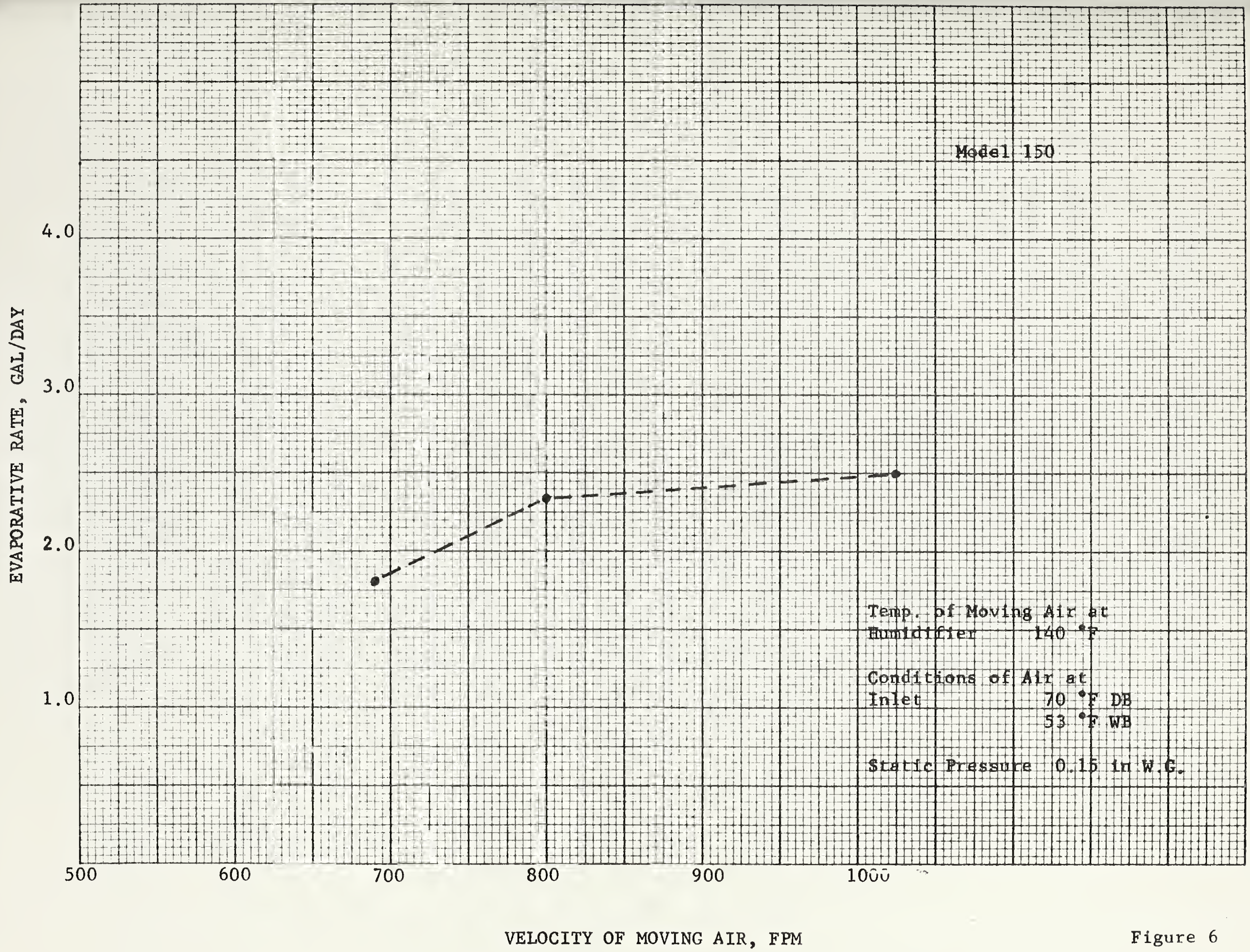

Model 150
EVAPORATIVE RATE, GAL/DAY
4.0
3.0
2.0
1.0
500
600
700
800
900
1000
Temp. of Moving Air at
Humidifier 140 °F
Conditions of Air at
Inlet 70 °F DB
53 °F WB
Static Pressure 0.15 in W.G.
VELOCITY OF MOVING AIR, FPM

Figure 6

5. Requirements for Residential Humidification

The evaporative capacity of a humidifier needed in a house depends on a number of factors such as:

a. <u>Volume of house being humidified</u>

b. <u>Air change rate</u>. The air change rate depends primarily on the openings and cracks that exist in a house. Many of the houses erected in the United States and Canada in the past 10 years have infiltration rates of one air change per hour or less.[1,2,3] The average house will normally have about 1.5 air changes per hour[2] and many of the older houses, which are more loosely constructed will have 2.5 changes or greater.[2]

Another important factor is the difference between the indoor and outdoor temperatures; the greater the difference, the greater the infiltration of air. The air change rate also depends on the direction and magnitude of the wind.

The air changes in a house is greatly affected by the opening of doors. A house with a large family will, without a doubt, have a larger air change rate.

The change of air is also affected by the type of heating system: all other things being equal, an all electrical house which does not draw air from outdoors for combustion of fuel will have a lower rate of air change.

c. <u>Amount of moisture in the outdoor air</u>

The amount of moisture in the outdoor air varies with geographic

location and outdoor temperature. In northern climates in the United States where humidifiers are most useful, the average dry bulb temperature varies during the winter months from about 15 to 40 °F[4,5] with occasional levels running as low as 10 or 20 deg F below zero. The average depression of the wet bulb temperature ranges from about 2 deg F to about 3 deg F during these months.[4,5] In sections of the United States such as Virginia, Missouri and Utah where temperatures are more moderate during the winter months, the dry bulb temperature averages from about 30 to 50 °F with occasional levels as low as about 0 °F.[4,5] The depression of the wet bulb temperature during these months averages about 3 deg F.[4,5] An approximate overall average for these two sections appears to be about 33°F dry bulb and 30°F wet bulb, or a relative humidity of about 70 percent. This combination of outdoor temperature and relative humidity is equivalent to about 15 percent relative humidity inside a house in which the dry bulb temperature is 75°F.

In the northern sections there are many days when the outdoor temperature is 0°F. The U. S. Weather Bureau advised in a communication by telephone that a typical value for relative humidity under this situation, and when there is snow on the ground, is about 80 percent. This is equivalent to about 3 percent at an indoor temperature of 75°F.

The ASHRAE Handbook of Fundamentals (1967) states that at 75°F indoor temperature, a person is most likely to be comfortable at relative humidities between about 25 to 40 percent.[6]

It will be necessary in many locations north of the Carolinas for a humidifier to supply the necessary water to raise relative humidity from about 15 percent to about 30 percent for an indoor temperature of 75°F. At 0°F in the northernmost section of the U. S. it will often be necessary for the humidifier to raise relative humidity from about 3 percent for an indoor temperature of 75°F. Some people, however, prefer indoor relative humidities as high as 35 to 40 percent in which case, a humidifier with an even greater capacity will be required. Humidities greater than 40 percent are not advised because of the possibility of condensation and damage to the house.

d. Other sources of humidity include clothes drying, clothes washing, cooking and moisture from people. The ASHRAE Guide [/2] shows that a typical drying of clothes contributes about 25 lbs of moisture and often when such drying occurs and if the moisture is not vented to the outside, there is no need for operation of the humidifier. The contribution by cooking and people is not nearly as great. The overall contribution from household operations has been estimated at 3 gal per day (1 lb/hr) [/7]. A factor which must be considered is the "flywheel" effect brought about in a house due to the hydroscopic characteristics of its contents. Even though a sudden dry spell occurs, there will be some time elasped before it is necessary to add moisture to the air.

e. Methods of calculation of amount of water required.

In making calculations of the amount of water required in a house, it is not possible to consider the variations in all of these factors which occur during a 24 hour period. There is no prescribed way to make allowances for variation in door openings, for example, and changes

in direction and velocity of the wind must be neglected. A statistical average of conditions is assumed, consequently, for which various formulas have been developed. The formula presented in the ASHRAE Guide and Date Book,[2] as shown below, has been used by many designers. This formula allows calculations for various size houses on the basis of assumed rates of air changes, neglecting the cause of the air changes, and assume selected and arbitrary temperature differences between the indoor and outdoor temperature. It also assumes a standard barometric pressure.

$$H = \frac{V}{13.5} R (w_i - w_o)$$

where:

H = pounds of moisture per hour required to maintain indoor design conditions.

V = air volume of house to be humidified, cubic feet.

R = number of changes of air per hour.

w_i = lb. of moisture per lb. of dry air at desired indoor conditions (from psychrometric chart applicable for atmospheric pressure of 29.92 in. Hg)

w_o = lb. of moisture per lb. of dry air at outdoor conditions (from psychrometric chart).

Table 7 gives required evaporative capacities, calculated with the use of the ASHRAE formula, for a number of selected sizes of houses, rates of air change, difference between indoor and outdoor temperatures, and relative humidity of the outdoor air.

Table 7

Gallons of water required per day to maintain 30 percent relative humidity in houses having an indoor temperature of 75°F.

ume of se, cu ft.	Difference between indoor and outdoor temperatures, deg F. 45 (Equivalent to 30°F outdoor temp.)			75 (Equivalent to 0°F outdoor temp.)	
	Air changes per hour	Outdoor rel. humidity % 50	70	Air changes per hour	Outdoor rel. humidity % 80
10,000	0.5	4.2	3.5	0.5	5.3
	1.5	12.6	10.5	1.5	15.9
	2.5	21.0	17.5	2.5	26.5
12,500	0.5	5.2	4.6	0.5	6.7
	1.5	15.6	13.8	1.5	20.1
	2.5	26.0	23.0	2.5	33.5
15,000	0.5	6.4	5.2	0.5	8.1
	1.5	19.2	15.6	1.5	24.3
	2.5	32.0	26.0	2.5	40.5
20,000	0.5	8.4	6.9	0.5	10.7
	1.5	25.2	20.7	1.5	32.1
	2.5	42.0	34.5	2.5	53.5

Table 8 gives information on required evaporative capacities, where R, the infiltration rate was determined on the basis of a formula which includes terms for wind velocity and outdoor temperature. This formula was developed by Coblentz and Achenbach/3 of the National Bureau of Standards. It was based on a study of 10 electrically-heated houses. The formula is specific for the 10 houses under study and may not be applicable for other houses or other electrically heated houses. The results of the table are indicative, however, of what could be expected under various conditions of wind speeds and outdoor temperature, in the case of relatively tight houses.

$$R = 0.15 + 0.013W + 0.005T$$

where: W = wind velocity, mph

T = difference between indoor and outdoor temperature, deg F.

These data were given primarily to show the effects of wind on infiltration of air into a house.

Electrically heated houses usually employ resistance heaters inside baseboard convectors as the source of heat, or they employ wall or ceiling panels with electrical grids. Under these conditions, furnace-bonnet types of humidifiers cannot be used. Many electrically heated houses in the past ten years, however, particularly in the northwest part of the United States, employ moving hot air as the heat-transfer medium. The air is heated by resistance heaters placed in a duct system and houses with these systems can use a humidifier of the type tested. Electrical houses generally have low infiltration rates.

Table 8

Gallons of water required per day in ten electrically-heated houses to maintain 30 per cent relative humidity at 75 °F indoor temperature, based on a study by Achenbach and Coblentz of the National Bureau of Standards.

Volume of house	Difference between indoor and outdoor temperatures, deg F: 45 (Equivalent to 30 °F outdoor temp.)			75 (Equivalent to 0 °F outdoor temp.)	
	Wind velocity (mph)	Outdoor relative humidity, (%) 50	70	Wind velocity (mph)	Outdoor relative humidity, (%) 80
10,000	0	3.1	2.6	0	4.0
	5	3.7	3.1	5	4.6
	10	4.3	3.5	10	5.5
	15	4.6	4.1	15	6.1
12,500	0	4.0	3.2	0	4.9
	5	4.6	3.8	5	5.8
	10	5.2	4.3	10	6.7
	15	6.1	4.9	15	7.5
15,000	0	4.6	4.0	0	6.1
	5	5.5	4.6	5	7.2
	10	6.4	5.2	10	8.1
	15	7.2	6.1	15	9.3
20,000	0	6.4	5.2	0	8.1
	5	7.5	6.1	5	9.5
	10	8.4	6.9	10	10.7
	15	9.5	8.1	15	12.1

6. <u>Comments on the evaporative capacities of the two humidifiers</u>

In evaluating the adequacy of a humidifier in a house, contributions of household operations which tend to augment the moisture supplied by a humidifier must be considered. The humidifier, on the other hand, in many cases is inoperative when the furnace blower is not operating.

It is difficult to place exact values on these two factors because of their sporadic and uncertain nature. Cooking, washing, drying, and the operation of the showers could occur coincidentally on one day and the humidifier will not be needed. On another day only cooking might occur and it is probable that the humidifier would be needed. On very cold days, the furnace and its blower will probably operate nearly continuously. On many days it will operate only 50 percent of the time, particularly in states below Montana, Wisconsin, Michigan and New York. Furthermore, some modern heating systems keep the blower operating continuously, and others are operated in this way by owners because they desire continious humidification, and for such systems the maximum output of the humidifier can be realized. The operating schedule therefore may cause the realized output of humidification to range from one half to full capacity of the humidifier, with a deficit in the case of the Model 40 unit of from zero to 5 gal/day. Thus, for this unit, an average deficit of about 2.5 gal/day in humidification is approximately counterbalanced by the estimated humidity augmentation of 3 gal/day (1 lb/hr) from household operations that was arrived at from studies at Purdue University. /7

These conclusions are the result of discussions with a representative of the American Gas Association and with engineers at the National Bureau of Standards. No data on blower operation appear to be available in the literature.

On the basis of the above information and that in table 7, it would appear that Model 40, which had an evaporative capacity of about 10 gal. per day, would be adequate for cases where houses of from 10,000 to 12,500 cu ft in volume have air changes of about 1 per hour, or less. This model would also be adequate for cases where houses of from 10,000 to 20,000 cu ft have air changes of 0.5 or less per hour. For houses having air changes of about 1.5 per hour which is considered about average for homes in the United States, Model 40 would be completely satisfactory only for those houses having volumes of 10,000 cu ft or less and where the outdoor relative humidity is 70 percent or greater for an outdoor temperature of 30°F.

Table 8 shows that for houses similar to the ten tightly-sealed and electrically heated houses used in the study of Colblentz and Achenbach, Model 40 would be completely satisfactory for house volumes of from 10,000 to 20,000 cu ft, when the wind velocity was 15 mph or less.

Model 150 which had an evaporative capacity of about 2 gal per day appeared to be inadequate for most homes.

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